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CERN@school: bringing CERN into the classroom

T. Whyntie[a,b], J. Cook[a,b], A. Coupe[a,c], R. L. Fickling[b], B. Parker[a], N. Shearer[d]

[a] *Langton Star Centre, Langton Lane, Canterbury, CT4 7AS, United Kingdom*
[b] *Queen Mary University of London, Mile End Road, London, E1 4NS, United Kingdom*
[c] *University of Southampton, Bassett Road, Southampton, SO17 1BJ, United Kingdom*
[d] *University of Durham, Stockton Rd, Durham, County Durham DH1, United Kingdom*

Abstract

CERN@school brings technology from CERN into the classroom to aid with the teaching of particle physics. It also aims to inspire the next generation of physicists and engineers by giving participants the opportunity to be part of a national collaboration of students, teachers and academics, analysing data obtained from detectors based on the ground and in space to make new, curiosity-driven discoveries at school. CERN@school is based around the Timepix hybrid silicon pixel detector developed by the Medipix 2 Collaboration, which features a 300 μm thick silicon sensor bump-bonded to a Timepix readout ASIC. This defines a 256-by-256 grid of pixels with a pitch of 55 μm, the data from which can be used to visualise ionising radiation in a very accessible way. Broadly speaking, CERN@school consists of a web portal that allows access to data collected by the Langton Ultimate Cosmic ray Intensity Detector (LUCID) experiment in space and the student-operated Timepix detectors on the ground; a number of Timepix detector kits for ground-based experiments, to be made available to schools for both teaching and research purposes; and educational resources for teachers to use with LUCID data and detector kits in the classroom. By providing access to cutting-edge research equipment, raw data from ground and space-based experiments, CERN@school hopes to provide the foundation for a programme that meets the many of the aims and objectives of CERN and the project's supporting academic and industrial partners. The work presented here provides an update on the status of the programme as supported by the UK Science and Technology Facilities Council (STFC) and the Royal Commission for the Exhibition of 1851. This includes recent results from work with the GridPP Collaboration on using grid resources with schools to run GEANT4 simulations of CERN@school experiments.

Keywords: CERN, education, outreach, pixel detectors, space weather, grid computing

1. Introduction

1.1. A brief history of CERN@school

CERN@school was conceived when students from the Simon Langton Grammar School for Boys visited the Medipix laboratories at CERN in 2007. After seeing the potential for using the Timepix hybrid silicon pixel detectors [1] for detecting and visualising ionising radiation in the classroom, a pilot project was established with the support of the South East Physics Network (SEPnet) and Kent County Council (KCC) that placed ten detectors in schools in Kent, England. Students from the Langton Star Centre, the research facility attached to the school and directed by B. Parker, then submitted a proposal for the Langton Ultimate Cosmic ray Intensity Detector (LUCID) experiment to a satellite competition for schools run by the British National Space Centre[1] and Surrey Satellite Technology Limited (SSTL). Consisting of five Timepix detectors arranged in an open-faced cube, LUCID was ultimately accepted as one of

Email address: `t.whyntie@qmul.ac.uk` (T. Whyntie)
URL: `http://cernatschool.web.cern.ch` (T. Whyntie)

[1] Now the UK Space Agency (UKSA).

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scientific payloads aboard SSTL's TechDemoSat-1.

In 2011, the UK Science and Technology Facilities Council (STFC) awarded LUCID a Science in Society Large Award to support the dissemination of data and the development of educational and promotional resources for schools. With the launch of TechDemoSat-1 delayed and additional funding secured, the opportunity was taken to expand the original CERN@school detector network. Twenty-five Timepix detectors, supplied by Jablotron[2], were procured and distributed around the UK via the Institute of Physics (IOP) Physics Teacher Network (PTN). In 2013, the Royal Commission for the Exhibition of 1851 Special Award was made to support the role of Schools Research Champion for the national network of detectors and LUCID. On Tuesday the 8th July 2014, TechDemoSat-1 launched successfully aboard a Soyuz 2b launch vehicle from Baikonur Cosmodrome, Kazakhstan. The satellite has since been commissioned and readied for operations in late October 2014.

1.2. The CERN@school philosophy

The philosophy that drives CERN@school is based on that of the Langton Star Centre, which consists of a group of laboratories, offices and meeting spaces at the Simon Langton Grammar School for Boys in Canterbury, Kent. The underlying principle is simple: *let students be scientists*. This is achieved by:

- giving students access to cutting-edge detector and computing technology through partnerships with the Medipix and GridPP collaborations;
- sharing data, knowledge, and tools from real scientific experiments such as LUCID and the Large Hadron Collider (LHC);
- allowing participating students and teachers to join a wider community of scientific and industrial partners as part of the CERN@school Collaboration;
- providing dedicated technical, project management and evaluation support for the CERN@school programme (as opposed to relying on the free time and goodwill of academic partners).

1.3. Overview of the proceedings

The remainder of this document serves to describe various aspects of CERN@school: the student-driven research programme, based on data obtained from Timepix detectors in schools and in space (section 2); the educational resources and activities associated with CERN@school (section 3), and; the role played by the GridPP Collaboration with respect to computing and data storage on the grid (section 4). A summary and conclusions are given in section 5, before acknowledgments are made to the many individuals and organisations who have made CERN@school what it is today.

[2]See `http://www.jablotron.com` for more information.

2. CERN@school in the laboratory and in space

2.1. The Timepix hybrid silicon pixel detector

CERN@school is based around the Timepix hybrid silicon pixel detector [1]. Developed by the Medipix 2 Collaboration, it consists of a $300\,\mu$m thick silicon sensor bump-bonded to a Timepix readout ASIC (figure 1). An array of 256-by-256 readout circuits, spaced with a pitch of $55\,\mu$m, define a grid of 65,536 pixels on the $1.98\,\mathrm{cm}^2$ sensor element.

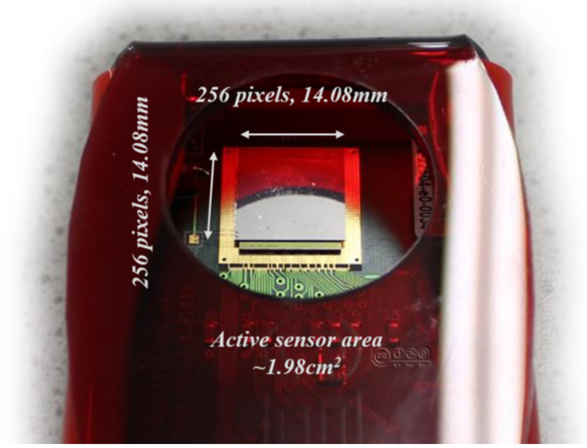
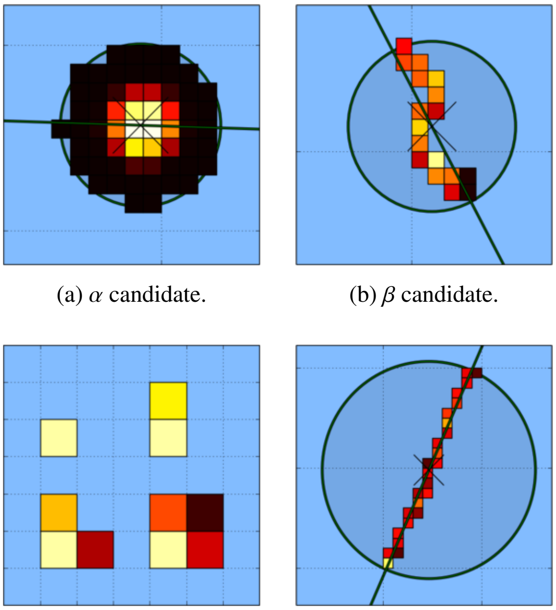


Figure 1: A close-up view of the CERN@school Mk1 detector, showing the silicon sensor element on top of the Timepix readout ASIC.

Originally developed for medical imaging applications, the Timepix detector can be used to detect ionising radiation, make energy measurements when calibrated [2, 3] and perform particle identification (to an extent) by analysing patterns in the pixels that record charge measurements. From an educational perspective, perhaps the most valuable function is the ability to visually distinguish different types of radiation. Figure 2 shows four types of Timepix *cluster* – group of adjacent pixels – corresponding to (a) alpha, (b) beta, and (c) gamma radiation, as well as (d) a candidate muon cluster.



(a) α candidate. (b) β candidate.

(c) γ candidates. (d) μ candidate.

Figure 2: Candidate clusters as displayed to the user in the CERN@school DAQMAP system. The circle indicates the extent of the cluster radius r_k from the cluster centre (x_k, y_k), and the line indicates the calculated line of best fit used to define the cluster linearity l_k. The colour of each pixel represents the number of counts measured; an arbitrary scale is used here for illustrative purposes.

2.2. The detector network

There are currently around thirty Timepix detectors in the CERN@school detector network. These are either the Mk1 detectors used in the SEPnet pilot or the Jablotron MX-10 Particle Camera units funded by STFC. The former are housed in a distinctive red acrylic casing developed by the Langton Star Centre; the latter in a grey casing with sliding plastic cover and 1/4" screw mounting. Both types are supplied with laptops for running the data acquisition software package Pixelman [4] when connected to the detector via the FitPix USB interface [5].

The detectors are distributed around the UK and managed by SEPnet university outreach officers or IOP Physics Network Coordinators (PNCs). These network "hubs" are trained to use the detectors and, in turn, train other students and teachers. They then have the freedom to design their own programme based on the specific requirements of their region. For example, some detectors may be placed in a school for a fixed period associated with a particular student research project, while others may be used as part of a series of educational demonstration workshops in multiple schools. Two detectors have also been deployed to the Daresbury Laboratory and the Rutherford Appleton Laboratory (RAL) for use in their respective outreach and engagement events.

2.3. The LUCID experiment

The five Timepix detectors of the LUCID experiment [6] offer students and teachers the opportunity to access and analyse data gathered in Low Earth Orbit (LEO) at an altitude of approximately 630 km. This data, which is shared with all members of the CERN@school Collaboration, will allow students to achieve the goals of LUCID's scientific programme, which include: measurements of particle intensity, energy, and directionality for use by the space weather community; studies of solar activity, and; investigations into the radiation environment of particular geographical areas of interest, such as the electron belts in the polar regions and the South Atlantic Anomaly (SAA). The ability to compare the measurements from space with measurements made on the ground by students themselves adds an additional pedagogical element to the programme; students are able to make a direct connection between what is being done with a remote instrument and the instruments that they control themselves.

3. CERN@school in the classroom

3.1. Demonstration experiments

The first point of contact with the detector for both students and teachers is generally the series of demonstration experiments that can be performed with the CERN@school detector. As well as serving as an introduction to using the detector to perform experiments, the activities are designed to be linked directly to the science curriculum. The list of experiments currently includes:

- **Inverse square law**: the gamma radiation from an Americium-241 source is used to investigate the inverse square law. By counting the number of single photon clusters (figure 2c) measured at different detector-source separations, the inverse square law can be tested. An extension activity involves correctly modelling the square geometry of the detector, as opposed to a disc. Further details may be found in [7];

- **Beta decay of Potassium-40**: ^{40}K undergoes beta decay, making substances with a high potassium content ideal as classroom-friendly sources of radioactivity. In figure 3, a CERN@school Mk1 detector has been mounted in a clamp stand over a

Petri dish of potassium chloride. Students can investigate the properties of the beta clusters detected (figure 2b). An extension activity involves comparing the measured clusters with those produced in GEANT4 [8, 9] simulations of the detector (figure 3, inset);

- **Attenuation of radiation by aluminium**: beta radiation from either a Strontium-90 source or potassium chloride is attenuated by aluminium shielding of varying thickness. It can be shown that the number of beta particles identified counted by the detector obeys the expected exponential decay as the thickness is increased;
- **Radiation profiles**: background radiation comes from many sources; for example, certain types of rocks and foodstuffs are known to exhibit very mild levels of radioactivity. In this experiment, students are encouraged to measure the radiation produced by samples of their choosing and characterise this in terms of the particle types and energies observed in the form of a radiation profile.

Many of these experiments have been developed by undergraduate students working as part of the CERN@school programme, either as part of their degree course or an independently organised summer placement.

3.2. Data management with the DAQMAP

Once familiar with operating the detector, students and teachers are encouraged to record their data, analyse it and share it with others via the Data AcQuisition, Management, Analysis and Presentation (DAQMAP) system. Based on the same technology as Galaxy Zoo [10], the DAQMAP is a Ruby on Rails web application running on an AWS Ubuntu 12.04 LTS server deployed with Phusion Passenger. Users, organised into research groups, can upload and download data sets via zipped ASCII text files. These are then filtered and processed by the server. Users may then inspect frames and clusters using a client-side display powered by Raphaël JavaScript library. Figure 2 uses examples from the DAQMAP cluster display. Functionality is also available for monitoring detector usage, submitting Support Tickets for feature requests and software bugs, reporting on CERN@school-related activities, and keeping equipment inventories. Students are also encouraged to perform local analysis of their data with code written in the Python programming language, which is made available through open source online code repositories.

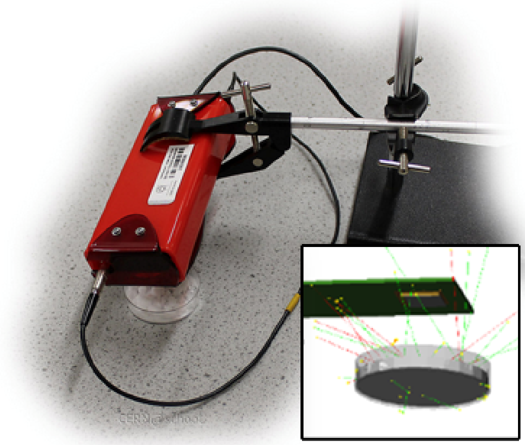


Figure 3: The experimental setup for investigating the beta decay of ^{40}K from a potassium chloride sample with the CERN@school Mk1 detector. The detector is held upside-down in a clamp stand, connected to the laptop running Pixelman [4] via the FitPix USB interface [5] (not pictured). The KCl sample is placed in a petri dish below the detector to minimize the risk of material falling on the sensor element. *Inset*: the same experiment simulated with the the Allpix GEANT4 [8, 9] software suite. The simulated detector is shown without the casing for clarity.

3.3. Research in schools

Resources are also provided to aid students and teachers in the running of research groups in schools, based on the methods used by active research collaborations. For example, guidelines have been produced for running weekly collaboration meetings, where results are shared and progress updates are given (often using video conferencing software when more than one school is involved). There are also materials available relating to presentation, poster and paper preparation. Research group wikis are encouraged for documentating and disseminating information relating to project work. On Monday 8th September 2014, the first annual CERN@school Research Symposium was held at the University of Surrey in conjunction with the 10th International Conference on Position Sensitive Detectors[3]. Over 100 students and teachers from around the UK presented results from projects including FAIR (Fractional Attenuation of Ionising Radiation), RAY (Radiation Around You), and LUCID. By attending an actual academic conference and presenting the results of their CERN@school work, students were given a genuine taste of the scientific process and the international nature of collaborative science.

[3]This occurred after the ICHEP 2014 conference, but is noted here for completeness.

4. CERN@school on the grid

4.1. The role of GridPP

CERN@school is supported by the GridPP Collaboration [11], which represents the UK contribution to the Worldwide LHC Computing Grid (WLCG). As part of the collaboration's commitment to engaging with the wider research community and industry, support is provided for non-LHC Virtual Organisations (VOs). Four out of the nineteen UK Tier-2 sites currently support the `cernatschool.org` Virtual Organisation.

The relationship between CERN@school and GridPP is mutually beneficial. One of the challenges of working in schools is the variability in the available computing infrastructure available. GridPP offer the `cernatschool.org` VO access to computing and storage resources and storage for large-scale data analysis and simulation work. In return, CERN@school acts as a flagship VO for non-LHC tool and policy development, and acts as a technology demonstrator when engaging new research and Small-to-Medium Enterprise (SME) VOs.

4.2. Simulating the LUCID experiment

To demonstrate with an example, GridPP resources were used run and store data from GEANT4 simulations of the LUCID experiment, building on the work described in [12]. This was done with the Allpix software suite developed by J. Idarraga, M. Benoit, and S. Arfaoui for the Medipix 2 Collaboration. Allpix provides a suite of tools for simulating silicon pixel detectors, including Timepix. For the LUCID simulations, five Timepix detectors and a portion of the LUCID geometry were simulated as shown in figure 4. Allpix was deployed to the grid with the the CERN Virtual Machine File System (CVFMS) instance at the RAL Tier-1 site, and the DIRAC [13] instance at the Imperial College London Tier-2 site was used for job and data management.

In this scenario, a typical LUCID Monte Carlo dataset consisted of 5 million source particles corresponding to the predicted flux and energy spectra of the electrons and protons present at a given orbital coordinate for ~ 500 orbital coordinates. These datasets were then used by students to study expected performance of LUCID in the South Atlantic Anomaly (SAA) and electron belts in the polar regions and prepare for for real LUCID data when it arrives from TechDemoSat-1, following the practice of most modern high energy physics experiments.

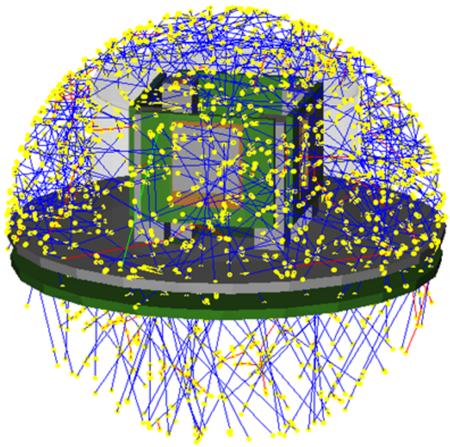


Figure 4: A visualisation of the LUCID experiment as modelled the Allpix GEANT4 [8, 9] software suite. The aluminium "dome" structure is not shown so that the Timepix detectors are visible. In this sample event, the General Particle Source (GPS) has generated a number of 40 MeV protons on the surface of a 5 cm radius hemisphere surrounding the detectors.

5. Summary and conclusions

Various aspects of the CERN@school programme have been described. CERN@school provides schools with Timepix detector technology with which they can make research-grade measurements of ionising radiation. There are currently thirty detectors in the CERN@school detector network, which is managed by the Institute of Physics Physics Teacher Network. Students and teachers also have access to data – both simulated and real – from the satellite-based LUCID experiment. Educational resources featuring demonstration experiments, open-source analysis code, and research practice guidelines are also made available to members of the CERN@school Collaboration. User data is shared and managed with the DAQMAP system, which also provides support and reporting mechanisms for students and teachers. Large-scale computing resources are provided by the UK's GridPP Collaboration for data analysis and storage; in return, CERN@school acts as a technology demonstration Virtual Organisation for other non-LHC experiments. CERN@school is made possible by the funding from STFC and the Royal Commission of the Exhibition of 1851 that supports the dedicated personnel required to run a programme that brings CERN into the classroom and lets students experience first-hand how science works.

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